Chalk-Ex: Transport of Optically Active Particles from the Surface Mixed Layer

Albert J. Plueddemann
202A Clark Lab, MS-29
Woods Hole Oceanographic Institution
Woods Hole, MA 02543-1541
phone: (508) 289-2789 fax: (508) 457-2181 email: aplueddemann@whoi.edu

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http://uop.whoi.edu

LONG-TERM GOALS

Determine the mass balance of optically active particles within the surface boundary layer and identify the processes responsible for particle redistribution.

OBJECTIVES

1. Perform manipulative experiments in which a known quantity of optically active particles are introduced at the surface and tracked over time and space. This approach effectively removes uncertainty in the production term of the mass balance equation.

2. Identify and quantify the relevant physical and biological processes that remove optically active particles from the mixed layer (e.g., vertical mixing, sinking, dissolution, aggregation, and grazing-related "repackaging" into fecal pellets).

APPROACH

The focus of the Chalk-Ex project is a sequence of multidisciplinary field experiments done in cooperation with W. Balch, C. Pilskaln and J. Goes (Bigelow Lab for Ocean Sciences) and H. Dam and G. McManus (University of Connecticut). Patches of optically-active particles were created within the mixed layer by dispersal of ground Cretaceous chalk (CaCO3) from the stern of a research ship. Two deployments were completed during each of two cruises: November 2001 and June 2003. Each deployment used ~13 tons of chalk to make a patch of ~2 km^2. The first deployment of each cruise was at a eutrophic site within the Gulf of Maine, and the second was at a mesotrophic site over the continental slope south of Georges Bank. Patch evolution was monitored using a combination of time series and spatial survey measurements over periods of 2–4 days. Each experiment included chalk deployments (Balch), spatial and aerial surveys (Balch *et al.*), deployment of drifting sediment traps (Pilskaln), measurements of grazing and aggregation from in-situ samples (Dam/McManus) and determination of the distribution of dissolved organic matter (Goes). Our part of the field work focussed on three issues: (1) Determining the surface forcing during and after each chalk deployment, (2) Tracking the chalk patch with Lagrangian drifters, and (3) Determining the temporal evolution of stratification and velocity in the upper ocean.

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WORK COMPLETED

The first Chalk-Ex cruise was completed during 10–19 November 2001 on the R/V *Endeavor* out of Portland, Maine. Two sites were occupied. The north site was near 43°50'N, 67°45'W and the south site was near 39°45'N, 67°45'W. The second cruise was completed during 12–22 June 2003, again on the R/V *Endeavor* out of Portland. The same two sites were occupied. Approximately 13 tons of CaCO3 were injected at each site on each cruise. Following the chalk deployments, the interdisciplinary research team conducted a variety of operations while the patch was being tracked and mapped.

Surface forcing was determined from shipboard meteorological observations. Mean meteorological variables were used to compute surface fluxes of heat and momentum using bulk formulas. Tracking of the patch was done by means of Lagrangian drifters which followed the near-surface flow (upper 1–10 m, depending on the drogue configuration) and transmitted their position in near real-time. The drifters were deployed near the center of the patch, immediately after the completion of chalk dispersal. Drifter positions were available onboard the ship during the experiment, and served as a reference for adjusting the survey legs to intersect the patch. Position information was also transmitted via Argos satellite, and these more complete data were used to produce high quality drift tracks for post-cruise analysis. Upper ocean hydrography was measured from an instrumented drifter deployed near the center of the patch. This drifter consisted of a small surface buoy with instrumentation for measuring temperature, salinity, and velocity suspended below. For the November experiment, where relatively deep mixed layers were anticipated, instrumentation was spread out over the upper 100 m with vertical resolution of 5–10 m. For the June deployment, instrumentation was "compressed" into the upper 60 m, with 4 m resolution in the upper 30 m. Additional temperature sensors available for the June experiment were attached to the Lagrangian drifters to better resolve horizontal variability.

RESULTS

November 2001, North Site: Surface conditions (wind speed 7–14 m/s, average heat loss 315 W/m^2) favored rapid vertical mixing, and the mixed layer depth (MLD) was maintained at 50–70m depth during the experiment (Fig. 1a). As a result, the chalk was rapidly diluted immediately after injection, and proved difficult to detect.

November 2001, South Site: Conditions during and following chalk injection (wind speed 4–7 m/s, average heat gain 40 W/m^2) were more favorable for chalk detection. During chalk injection, the MLD was near 20 m, but within a few hours it shoaled to about 5 m due to horizontal advection (Fig 1b). The MLD dictated the initial penetration depth of the chalk, but patch development during the first 48 hours was controlled primarily by horizontal advection during a period of restratification.

June 2003, North Site: Surface conditions (wind speed 3–5 m/s, strong diurnal heating) resulted in a relatively steady MLD of less than 5 m during the first 2 days of operations (Fig. 1c). A sharp thermocline was seen near 20 m depth, and strong, high-frequency (10–40 min) internal waves were associated with this interface. Winds began to increase about 18 h after chalk deployment, eventually driving the MLD deeper. Increased vertical mixing and near-surface shear associated with this wind event spread the chalk to undetectable levels by the time of the final survey at about 57 h after deployment.

June 2003, South Site: Conditions just after chalk deployment (wind speed 4–6 m/s, strong diurnal heating) were favorable for maintaining a shallow MLD (less than 5 m; Fig. 2d). Winds were variable (1–10 m/s) over the next 3 days, during which the MLD varied from 5–15 m. The thermocline at the south site was more diffuse than at the north site, and internal wave activity was not as pronounced. The patch at the southern site was detectable for at least 48h after injection.

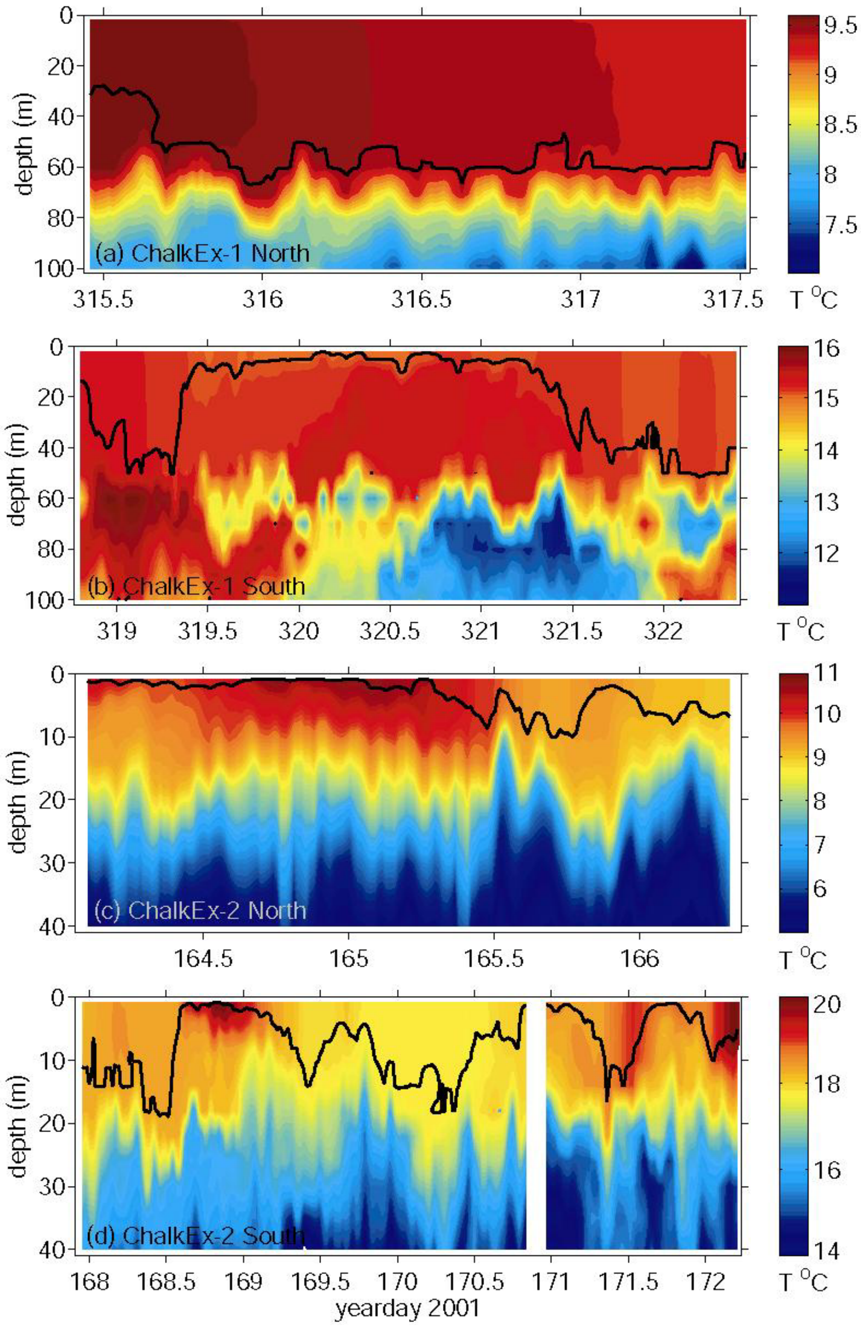

Figure 1. Temperature variability during ChalkEx as observed by the hydrographic drifter. Black line represents the mixed layer depth. [Four panels show color contours of temperature vs. time and depth for the four ChalkEx experiments. The presentation is meant to highlight differences in stratification, as described in the text.]

IMPACT/APPLICATIONS

These experiments are designed to quantify the major loss terms for optically active particles. This knowledge is critical to understanding the evolution of the optical field and for prediction of underwater visibility on horizontal scales from 1 m to 10 km, vertical scales from 1 to 100 m, and temporal scales of hours to days. The data demonstrate how important physical conditions are to the initiation and retention of a highly reflective coccolithophore bloom.

RELATED PROJECTS

This proposal is closely related to those of Balch/Pilskaln and Dam/McManus. We are working together to analyze results from the ChalkEx cruises. During year 1 of this project, the NASA MODIS team funded Balch to do chalk seeding studies for calibration/validation of the MODIS suspended calcite algorithm. The NASA project paid for the 26 T of chalk and some of the ship time for the November 2001 experiments. A small surface buoy design developed for the Remote Environmental Monitoring UnitS (REMUS) vehicle program was adapted for use with the instrumented drifter. Instrumentation obtained as a part of an NSF Major Research Instrumentation grant was used to upgrade the T-only measurements originally proposed for the instrumented drifter to T/S measurements.

PUBLICATIONS

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